Fall 2020

Use of Sulfur in Soybean Fields and its Association with Soil Types

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Creative Component Project

Use of Sulfur in Soybean Fields and its Association with Soil Types

by

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A creative component submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Agronomy

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Iowa State University
Ames, Iowa

November 27, 2020

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Abstract

Over the years sulfur deposition from the air has been on a continuous decline. This is significantly due to the Clean air act of 1970.The decrease in sulfur deposition has led to a decrease of sulfur in the soil and consequently has lowered sulfur intake for plants. Sulfur is a key nutrient in plants, including soybeans, and low sulfur content can lead to a decrease in overall yield. Studies have been performed by adding sulfur to soybeans, but the results vary across the board on if additional sulfur increases soybean yield. The question this research will try to prove is, soybean yield response to sulfur fertilizer depends on soil type. To test this hypothesis randomized block field trials were set up to test one hundred pounds of ammonium sulfate (AMS) compared to the control of zero pounds across two soil types of Brookston and Crosby. Brookston and Crosby types were chosen for their difference in organic matter. The results showed there was no significant difference in yield by soil type comparing the AMS to the control. The results did show there was an economic advantage to applying AMS to the Crosby soil type. This field trial showed research needs to include statistical analysis and an economic analysis to show the true findings.

Introduction

Rationale

Over the years, soybeans have been the “easy” crop that is planted and harvested but not managed in central Indiana. With the decline in the corn and small grain market, our farmers see it as a time to start managing their soybean crop or stop growing it at all due to the drop in profitability. In central Indiana, for the past five years, soybean yields have been at a plateau. Although the yields are good, the farmers want to create a profit. They want new ways to better manage their soybean crops and be profitable. Some farmers are investigating managing soybean nutrient applications based on biweekly tissue test levels. This approach has shown promise, but our farmers want a more easily implementable practice. Farmers are also evaluating early nitrogen applications to boost soybean crop development before nodulation. These two practices have shown promise for some farmers. Our goal was to find a way to raise soybean yields without adding additional equipment passes, with fertilizer, unless necessary. Meaning there was a positive response to added nutrient application or profit.

Sulfur is essential for the development of nitrogen fixing nodules on soybeans, the production of chlorophyll, and in producing essential enzymes. Sulfur deficiencies reduce protein formation within a plant (Marschner, 2012), decrease stress tolerance and ultimately decrease yields. Chlorosis, a sulfur deficiency symptom, appears in both old and young leaves because sulfur is mobile in the plant. Sulfur deficiencies increase the chances of reduction in yield on soybeans. In recent years, the soybean market has seen a steady decline in market price. Though the market has declined the inputs for growing soybeans has not. Inputs like seed, equipment cost, and fertilizer have not seen the decline in price. With the small margins between expenses and the price the grain is sold at market there is no room to lose yield. Every bushel counts more and more today and if we can find an economical way to increase soybean yields this could be the factor for net profit for some farmers.

Recent weather patterns in central Indiana have reduced the number of days suitable for fieldwork. Springs are wetter than normal, and this limits the time for fertilizer application, spring tillage, and spraying for burndowns. Thus, farmers would like to combine supplemental nutrient fertilizer application with one of the operations already made on the field. Farmers need to focus on the most limiting factor to increase their yields and I believe, in some fields, sulfur is the next most limiting factor. Sulfur can be applied with spring or fall fertilizer, fall gypsum passes, or in fertigation passes. The many products and forms of sulfur fertilizers make it possible to apply it at different times. A few of the products are elemental sulfur, gypsum, ammonium sulfate, and thiosulfate.

Objectives

1. Evaluate soybeans response to added sulfur fertilizer to the crop.
2. Determine which soil types respond the best to sulfur applications to soybeans.

Background

The atmosphere is composed of different forms of sulfur. These forms include carbonyl sulfide, hydrogen sulfide, sulfur dioxide, dust particles and other sulfur gases. Sulfur is usually oxidized into sulfates and returned to earth by rain. If there is enough Sulphur in the atmosphere, these processes can create acid rain. Acid rain generated problems with our natural landscape of forests and lakes and the government had to act (Brady and Weil, 2017). The Clean Air Act of 1970 was a pivotal point in addressing air pollution. This Act was the beginning of a decline in acid rain caused by reductions of industrial plant emissions. What this meant to farmers was that the sulfur that we had been receiving in large quantities was soon going to be minimal. According to Casteel and Camberato (2017), most of Indiana received thirteen pounds of sulfur per acre as deposition from the air in 2001. However, by 2015 sulfur from air decreased to below ten pounds per acre, and atmospheric S depositions has since then continued to decline steadily. This is not just a problem in Indiana, but across the whole United States. Barker and Sawyer (2002) measured an annual sulfate precipitation of 11.8 to 15.4 pounds per acre between 1971 and 1973. This amount of sulfur in the rain has the potential to replenish what most crops remove in their grain in a year (Barker and Sawyer, 2002). The USGS National Atmospheric Deposition Program reported precipitation of 2.4 to 4.2 pounds of sulfate per acre during the period from 1998 to 2001 (NADP, 2002). This is 2.5 to 5 times lower than what was measured thirty years ago. How much of the atmospheric deposits of sulfur is used by the soybean crop? For every ten bushels of grain 1.7 pounds of sulfur is removed with the soybean grain (Casteel and Camberato, 2017). With the decreasing sulfate deposition through precipitation, soil sulfur depletion from prolonged cropping, low or no fertilizer inputs, and declining soil organic matter, farmers have to rely more and more on organic matter mineralization, profile sulfate, and sulfur inputs to receive the sulfate their crops need (Barker and Sawyer, 2002).

Plants can uptake both organic and inorganic forms of sulfur (Brady and Weil, 2017). Organic sulfur is mineralized to plant available form sulfate sulfur (SO_4^{-2}) in soil (Franzen, 2018). This is the oxidized form of sulfur. The rate at which sulfur is mineralized is similar to the nitrogen cycle (Brady and Weil, 2017). Like the nitrogen there is a critical carbon to sulfur (C/S) ratio. This ratio is between three hundred and four hundred to one C/S (Brady and Weil, 2017). If the ratio goes above 400/1 then sulfur will be immobilized until the excess carbon is used and the ratio drops below the critical level (Brady and Weil, 2017).

There are many factors that affect the sulfur mineralization rate: moisture, aeration, temperature, and pH. When all these components become favorable then the organic form of sulfur will be converted into sulfate through microbial processes. The microbial process will fluctuate with the changes in moisture, aeration, temperature, and pH and may not meet the potential sulfur requirement needs of the crops (Brady and Weil, 2017). This is one reason to consider supplying sulfur through fertilizer to the crops. Another issue with sulfur fertilization is that the sulfate ion is negatively charged and is not bound to the negatively charged soil particles. Thus, it can easily leach from the soil profile during rainfall. Additionally, coarse-textured soils with low organic matter may not mineralize enough sulfur (Harward and Reisenauer, 1966).

Given that several variables affect sulfur availability, the next question is, when does the sulfur increase the grain yield? Boem, et al (2007) reported that sulfur deficiency during the seed filling period in soybeans affected the crop growth during seed fill and resulted in a reduction of seed yield. Gates and Muller

(1979) found that sulfur was important in nodule formation early in soybean crop and high levels of sulfur, phosphorous, and nitrogen promoted and favored nodulation.

In the last decade, there has been a push to add sulfur to crops like wheat and corn. Until recently there has been no serious effort on adding sulfur as fertilizer to soybeans. In the last three years yield responses in soybeans was observed when sulfur was included in the fertilizer plan. A 60-bushel soybean crop removes about 10.2 pounds of sulfur in the grain. This is more than what is deposited from the air. If 3 pounds of sulfur is received from the atmosphere, there is still a need for 8.9 pounds of sulfur that must come from alternate sources. The question is will our soil be able to give us the additional sulfur required to produce the yields our famers want? With increasing yields from high yielding varieties of soybean crops today more and more sulfur is expected to be removed through the grain, and there will be an increased need for added sulfur through fertilization. An alternative source of sulfur is through organic matter mineralization, which is dependent on microbial populations, warmer soil temperatures, and moisture. As more soybeans are being planted during cool and wetter soil conditions, there is less potential for sulfur undergoing mineralization process. Cooler soil temperatures with earlier planting windows may not provide adequate and timely supply of sulfur to plants.

Soybean field trials conducted by Dr. Shaun Casteel, in 2017, at Purdue University involved application of 100 pounds of ammonium sulfate (AMS) three weeks before or after planting to supply the soybean crop sulfur when mineralization was low. A zero to twelve bushels increase in yield was observed as a result from this application. In 2000 and 2001, Sawyer and Baker (2002) conducted sulfur strip trials in Iowa. Calcium sulfate and elemental sulfur fertilizers were broadcasted at rates of 0, 10, 20, and 40 pounds per acre in spring of 2000. They observed no significant yield gain to the sulfur application at the six test locations. They concluded that sulfur fertilization was not expected to improve soybean yields across Iowa soils. However, they did note that there was a missing component to the study. The manure currently applied to a large crop acreage in Iowa would be an important sulfur source and would lessen the need of sulfur fertilizers. No fields that were in their study had a history of manure applications. In soils low in organic matter and coarse textured, Sawyer and Barker (2002) found soybean crop to be responsive to sulfur applications. Granade and Sweeney (2008) did a similar study on group four and group five maturity soybeans in 1986 and 1987 on soils with high clay content and similar soil characteristics. An accumulation of extractable sulfate in the soil was seen when sulfur fertilization was used, and a response was seen more in areas of low organic matter. Kaiser and Kim (2013) ran replicated strip trials to see if there was a response to sulfur fertilizer applied as a broadcast or starter on sandy and finer soil texture soils. They observed increase in soybean grain yield because of sulfur application at one of the four sites. The yield response was seen at the location with the low organic matter.

As farmers push for higher yielding crops it is evident that the need for sulfur will increase. Parts of the world are already recognizing that sulfur is the next limiting nutrient after nitrogen (Brady and Weil, 2017). With the decline in sulfur in the air, soil test levels, and our crops we are in dire need to add sulfur to the soil fertility or nutrient management plan.

There are still many questions related to soybean's need for sulfur that remain unanswered. The primary questions are: 1) why some fields exhibit a response and others do not 2) is the variability in response to added S due to soil types, 3) does type of fertilizer source matter, and 4) is the planting date a factor? These questions will take time to answer, and they cannot all be answered with one strip trial study. Therefore, our intention is to focus on addressing the first two questions.

Initial Approach

I believe with prolonged reductions in sulfur accumulations from atmosphere and crop removal there will be fields where soybean yield response to sulfur application is possible. Replicated strip trials are a good approach to observe a yield response from the addition of sulfur fertilizer. Within the replicated strip trial, yield data can be evaluated in two ways: 1) observe yield response between areas of sulfur application and areas with no sulfur application and 2) observe effect of different soil types receiving S application on yield response. This will enable us to test the hypothesis that soybean yield response to S fertilizer depends on soil type.

The research trial includes four research fields in Shelby and Johnson County, Indiana. Two soil types were tested: Brookston and Crosby. The sulfur application strips will be placed in the field where the Brookston and Crosby soil types are present. All strips will be placed to evaluate the control and sulfur application on both the Brookston and Crosby soil type. The research design will be a randomized complete block design. Each block or replication comprise of all experimental units within a given area (Kyveryga, Mueller, and Mueller, 2018). For this experiment, each, of the three replications, will have the same trend of soil properties, soybean variety, and history. This means all treatments and factor combinations will be present in each replication to allow for rational judgments between the sulfur application and control. There will be as many control strips as there are treated strips on the same soil types. The control will provide a standard reference of practice to each treatment in its replication (Kyveryga, Mueller, and Mueller, 2018). Each field will have at least three, twenty-four-pound sulfur strips and three, zero sulfur check strip on each soil type. Moreover, having at least three strips of treated and control on each soil type will ensure that all strips will not be lost if there is a potential negative environmental factor. The replication is also necessary to perform a statistical analysis on the data (Kyveryga, Mueller, and Mueller, 2018). The replications are randomized to minimize any bias from knowledge of the location or unknown factors and for dispersing any spatial variability as well.

The fertilizer will be spread at 80 feet wide. Each of the check strips and sulfur strips will be 160 feet wide. Once the trials' application maps are made, soil types will be listed and evaluated based on organic matter. The sulfur product used will be one hundred pounds of ammonium sulfate (AMS) providing twenty-four pounds of sulfur and twenty-one pounds of ammonium nitrogen. Ammonium sulfate was chosen because of its availability and sulfur being in the sulfate form. It was ruled out that the nitrogen would have any effect on the soybean crop because in previous years, farmers in the area conducted trials with nitrogen on soybeans and observed no yield increase from a nitrogen application.

The AMS application window will be three weeks before or after planting. During this 6-week time period the fertilizer will not be applied during emergence to prevent a reduction of stand that could cause an error in the results. Date of application will be documented along with planting date. At R3 maturity of the soybeans, tissue samples will be taken to check levels of sulfur in the tissue along with the other nutrients to make sure there is not a deficiency that will skew the results. From the tissue analysis a sulfur and nitrogen ratio of the area will be determined. An aerial flight will be flown at R3, as well, to see if there is any visual evidence to the strips with added sulfur. The flight will be flown by a plane and by a DJI Phantom 4 Pro drone. The drone image will be a true color image (RGB) and plant health image, computer created NDVI image. The plane will be taking a RGB photo and then running a computer algorithm to create the plant health image. If the farmer is going to make any applications to the field, they must be done across the whole field with the same product. This includes but is not limited to herbicide applications, fungicide application, and in season fertilizer applications. No additional trials will be allowed in the field with the sulfur strip trial fields. To prevent any other nutrients from being limiting factors all fields have been soil tested in the last two years. Soil tests came back with an analysis on macro and micro-nutrients in the soil along with pH, total exchange capacity, base saturation, and organic matter percent. The fields have been and are fertilized based off the soil test data to provide adequate nutrients to each year's crop. When fields are harvested there will only be one combine harvesting the field to prevent any type of error between combine calibrations. The combine will be calibrated in the field to prevent any type of calibration error from previous fields.

After harvest, the yield data will be collected and analyzed from the control and treated strips and from different soil types. Harvest maps will be overlaid with ammonium sulfate application maps to find the average yield. This will be done using Ag Leader SMS software. Harvest maps will then be overlaid on soil type maps to find the average yield per soil type within each strip and will also be done using Ag Leader SMS software. The soil type maps are SSURGO soil type maps that have been ground truthed and edited if the soil types were not correct. Sulfur strip average yield data will be analyzed for treatment significance with PROC MIXED using SAS ver. 9.2 statistical analysis software. Once the data is analyzed, I will meet with the farmers to discuss their results. They will be given a binder with application maps, tissue test levels, harvest maps, and statistical analysis data from the sulfur strips and soil type analysis. After all data is analyzed it will be compiled into one report to compare the sulfur strip trials across the multiple fields in the study. To reduce the cost of this research trial for my farmers, I will enroll them in Indiana's INfield Advantage program for replicated sulfur trials in soybeans. This will be INfield Advantage's Tier Three program. This program is funded by Indiana check-off dollars. This will allow the aerial imagery and tissue sampling to be done at no cost to the farmer. The only cost to the farmer will be 100 pounds of ammonium sulfate fertilizer plus the application cost. On average the AMS product costs $0.15 a pound. This means the trial will cost the farmers $15 an acre where the AMS is applied. If the AMS can gain the farmer two to three bushels an acre, the product and application will pay for itself.

Revised Approach

The initial planned approach required a significant revision due to weather issues of 2019. The Spring of 2019 was extremely wet and cold in central Indiana. By May 26, 2019 there was only twenty-nine percent of the nation's soybean crop planted (U.S. Department of Commerce and Agriculture, 2019). This is behind forty-five percentage points from the nation's five-year average (U.S. Department of Commerce and Agriculture, 2019).

This caused planting to not only be delayed, but also for many fields to be enrolled in Prevent-Plant Programs. As a result, all farmers except one dropped out of the research study due to either delayed planting or planned soybean fields being converted to corn. Along with trial acreage reduction due to weather, INfield Advantage Tier Three program was cancelled, which resulted in termination of funding for the research trials. Consequently, no aerial imaging from a plane was captured, just the Phantom 4 Pro drone data was obtained. Tissue and soil samples were collected from three treated Crosby, three control Crosby, three treated Brookston, and three control Brookston soil types that totaled three replications of treated and control strips. The tissue and soil samples were taken at R3 soybean maturity. No soil tests were taken before planting due to bad weather and no soil samples were taken after due to loss of funding.

Expected Results

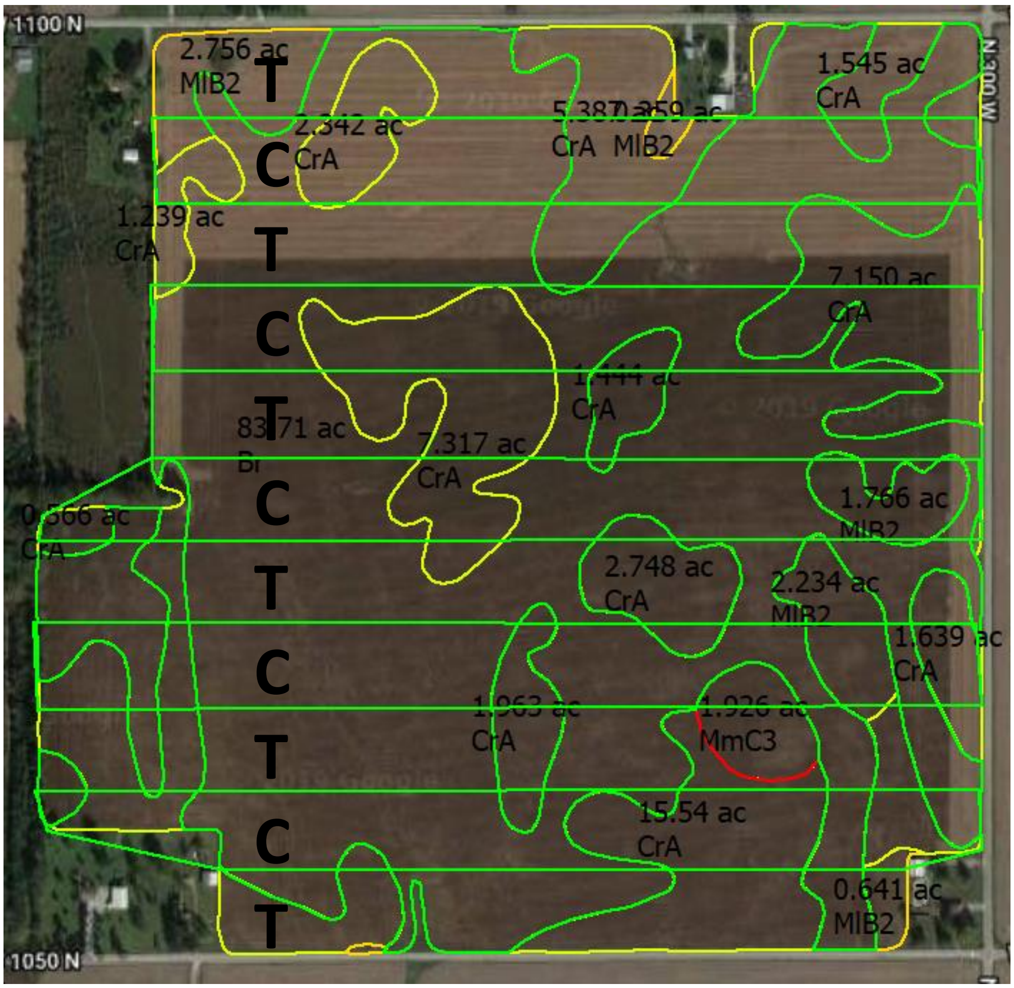
We expected to see a positive soybean yield response to ammonium sulfur application (AMS) at some of the sites from the Crosby soil type because of the lower organic matter compared to the Brookston soil type. The lower organic matter percent results in a lower sulfur mineralization throughout the year, thus allowing added sulfur an opportunity to play a role in increasing yields. Sulfur levels (in tissue test) were expected to be higher in areas that received the AMS compared to areas that were not treated. Since sulfur is highly mobile and easily leaches through the soil, no residual sulfur effects from previous year's crop applications on this study were expected to occur.

Results and Discussion

The one research plot that was able to remain in the study was a 142.38-acre field located in Shelby County, Indiana.

The AMS application was made before planting on May 22, 2019 with 100-pound AMS strips made across the whole field running east and west. The strips alternated treated and control with treated being the first strip on the north end of the field. The treated strips were 240 feet wide with 240-foot control strips dividing each. There was a total of six treated strips in the field. The Brookston soil type is labeled Br in figure 1 while Crosby is labeled CrA. The field was planted on May 28, 2019 with a 3.1 maturity soybean. The furthest north treated, and control strip were removed from the study due to the farmer changing the soybean to a 2.5 maturity soybean in those strips. Due to funding limitations, I

Figure 1. AMS Application Map.



was unable to analyze two different maturity soybeans in the same research study. The research field reached a R3 maturity level on August 8, 2019. On that date, tissue samples and soil samples were taken from a treated and control strip. Due to the loss of funding, only two strips were able to be analyzed: one treated strip and an adjacent control strip. The strips chosen contained similar topography and soil types. In each strip, a sample was taken from a Crosby soil type and a Brookston soil type. The samples were packaged and shipped same day to Brookside Laboratories in New Bremen, Ohio. They arrived at the lab on August 9, 2019 and data was received on August 12, 2019 for all samples taken.

Figure 2. RGB Drone Image of Research Field.

The results for soil and tissue analysis are presented in Tables 1, 2 and 3, 4, respectively. The laboratory results reports are available in the appendix. On the same day, a drone was flown over the field to create an aerial image of the field.

The image was stitched together through Drone Deploy and a RGB image and a plant health image was created. The plant health image allows for the contrast in the RGB image to be changed to bring forward differences or variability in the field.

Figure 3. Plant Health Drone Image of Research Field.

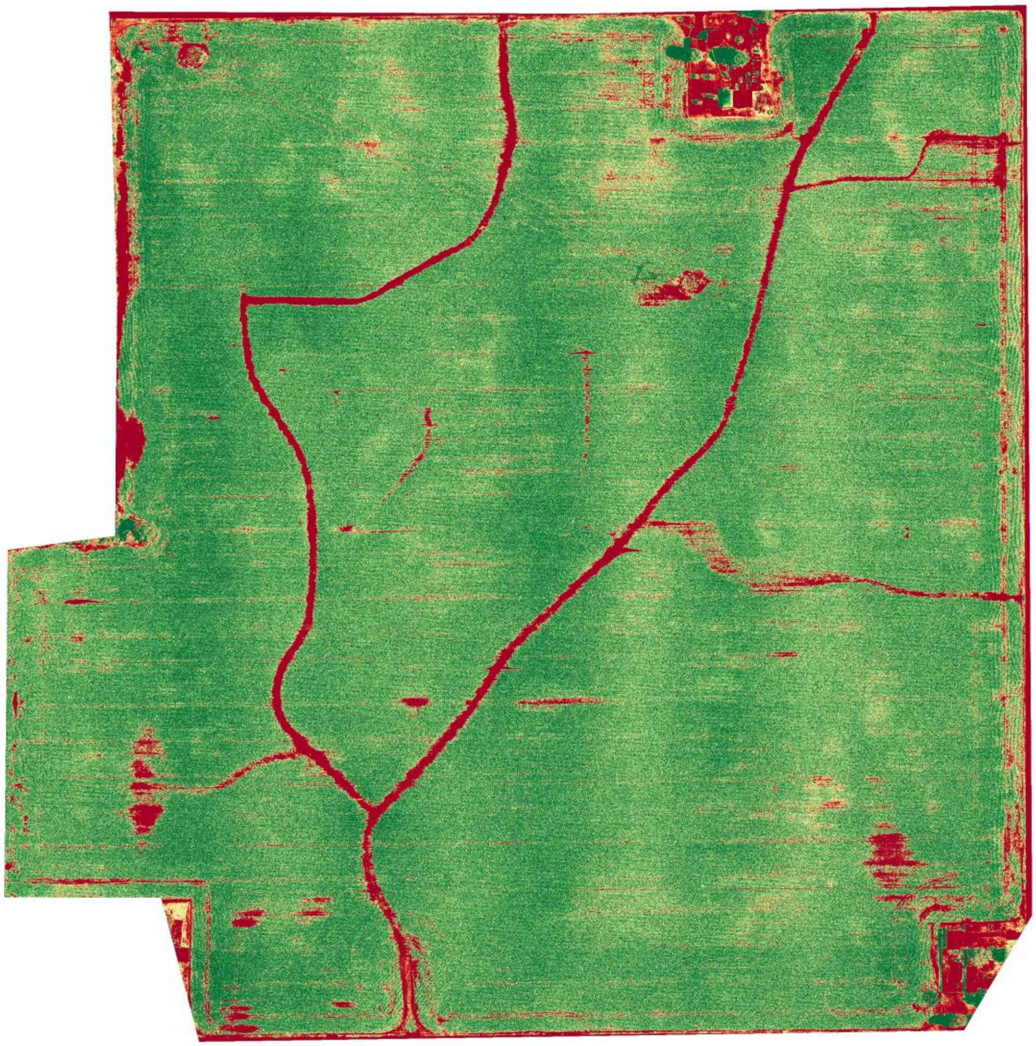


Figure 3 did not show increased visual signs from the treated areas when the contrast of the RGB photo was enhance. The dark green vertical lines that run north and south are from the drone taking images on an overcast day. The plant response to sulfur application can be picked up in faint light green lines running east and west on figure 2. The light green lines reflect the control areas, and the dark green lines indicate AMS application areas. The RGB image indicates increased chlorophyll from the AMS application.

The soil results show there is a difference on sulfur content in the soil at R3 soybean maturity for both the Crosby and Brookston soil types (tables 1 and 2). The sufficient ranges for leaf tissue content of sulfur are 0.2-0.35%. No sample shows levels of deficiency (tables 3 and 4). Along with, there is not a difference in sulfur content in the leaf tissue between the treated and control tissues for both the Crosby and Brookston soil types.

Harvest was started on September 28, 2019; however, due to wet weather, harvest was stalled and did not finish until October 4, 2019. The strips that were sampled, were harvested on October 4, 2019.

Table 1. Macronutrients and Base Saturation contents in control and treated plots based on soil types.

Treatment	Soil type	Exchange capacity	pH	Organic matter	Sulfur	Phosphorus	Base Saturation		
							Potassium	Calcium	Magnesium
		meq/100g	soil: wate	%	mg/Kg	mg/Kg	%	%	%
Control	Crosby	10.89	7.30	2.22	6.00	18.00	1.84	68.27	29.31
Treated	Crosby	10.85	7.40	1.91	13.00	16.00	2.29	65.76	31.41
Control	Brookston	18.15	6.30	3.29	8.00	83.00	2.50	77.22	19.97
Treated	Brookston	15.65	6.10	3.40	12.00	52.00	2.57	76.42	20.66

Table 2. Micronutrients levels in control versus treated plots based on soil types.

Treatment	Soil type	Boron	Iron	Manganese	Copper	Zinc	Aluminum
		mg/Kg	mg/Kg	mg/Kg	mg/Kg	mg/Kg	mg/Kg
Control	Crosby	0.42	127.00	64.00	4.68	1.62	617.00
Treated	Crosby	0.49	108.00	64.00	5.59	2.12	659.00
Control	Brookston	0.71	233.00	12.00	8.15	3.01	967.00
Treated	Brookston	0.52	171.00	13.00	7.07	3.09	873.00

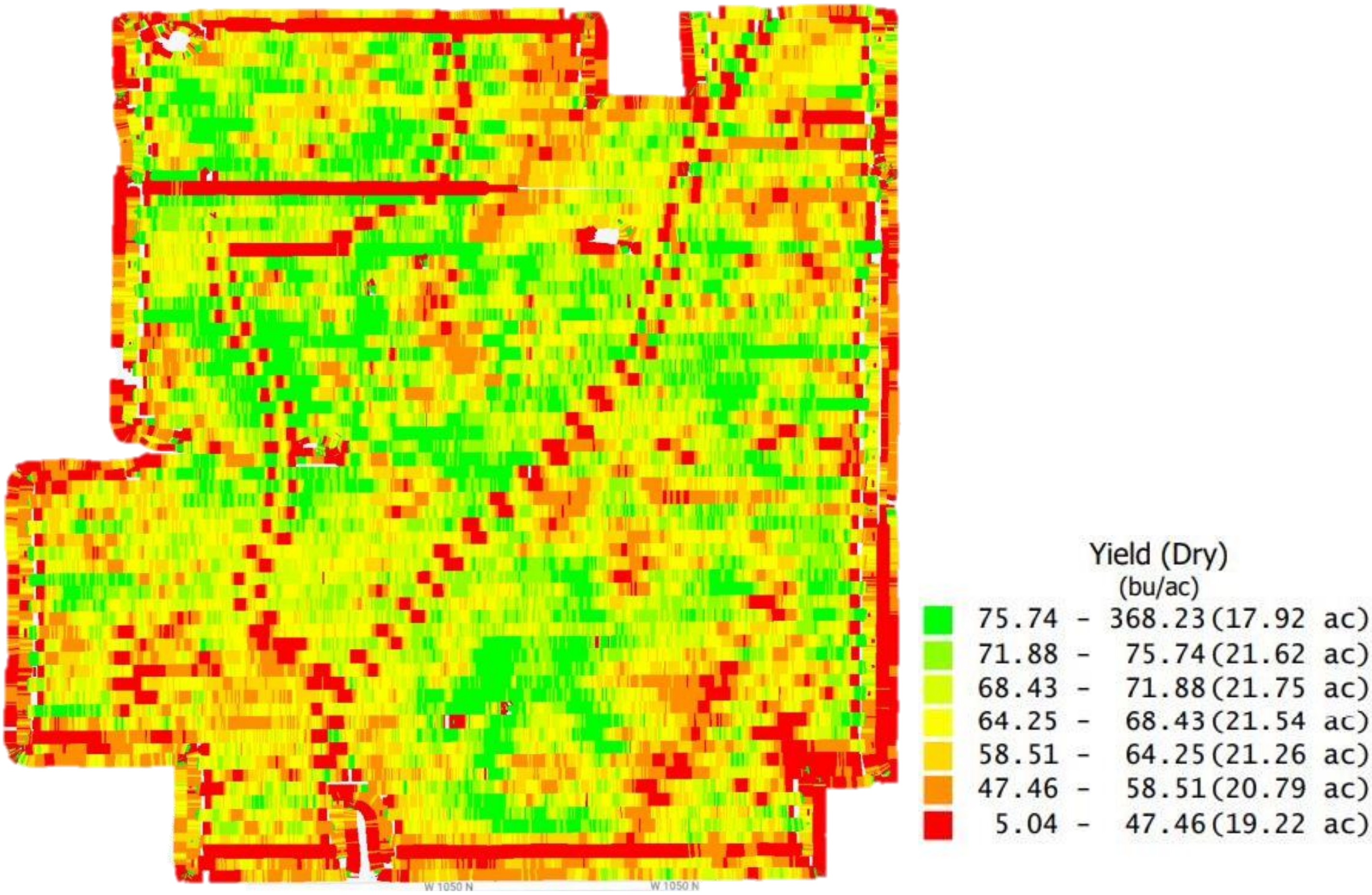
Table 3. Macronutrients and base saturation levels in tissues from control and treated plots from two soil types.

Treatment	Soil type	Sulfur	Nitrogen	Phosphorus	Base Saturation		
					Potassium	Calcium	Magnesium
		%	%	%	%	%	%
Control	Crosby	0.3235	5.695	0.4545	1.415	1.095	0.5265
Control	Brookston	0.2925	6.095	0.4615	2.295	1.025	0.3665
Treated	Crosby	0.349	7.555	0.4525	1.735	1.130	0.462
Treated	Brookston	0.3235	6.105	0.4545	1.850	1.08	0.5825

Table 4. Nutrient concentrations in tissue from control and treated plots from the two soil types.

Treatment	Soil type	Boron	Iron	Manganese	Copper	Zinc	Aluminum	Sodium
		mg/Kg	mg/Kg	mg/Kg	mg/Kg	mg/Kg	mg/Kg	mg/Kg
Control	Crosby	43.2	98.8	46.55	8.1	38.35	18.35	13.6
Control	Brookston	40.6	89.05	29.0	8.45	39.8	14.15	10.75
Treated	Crosby	40.05	100.65	40.35	8.75	39.05	15.45	14.1
Treated	Brookston	43.7	96.3	34.55	8.65	42.1	21.75	13.95

Figure 4. Yield Map of Research Field



The yield from entire research field averaged 62.71 bushels per acre with an average moisture of 11.76%. Each treated and control strip was 10.87 acres. Table 5 shows the control strips averaged 66.93 bushels per acre with a 12.02 percent moisture. Table 6 shows the treated strips averaged 66.51 bushels per acre with a 11.36 percent moisture. Two hypotheses were tested to observe if there was a statistical difference between the control and treated plots: HO: μcontrol = μtreated, the true population mean yield of the control plots is the same as that of the treated plots. As well as HA: μcontrol $\neq$ μtreated, the true population mean yield of the control plots is not that same as that of the treated plots. In table 7 row 1 the p-value (0.838) > α (0.05) and failed to reject the null hypothesis. There is no significant difference in the true population mean yield between the control and treated plots.

Table 5. Yield and grain moisture content from control strips for combined soil types across whole field.

Treatment	Yield (bu/ac)	Moisture (%)
Control	65.75	11.97
Control	68.04	12.58
Control	66.99	11.52
Average	**66.93**	**12.02**

Table 6. Yield and grain moisture content from treated strips for combined soil types across whole field.

Treatment	Yield (bu/ac)	Moisture (%)
Treated	69.79	11.84
Treated	65.69	11.27
Treated	64.06	10.96
Average	**66.51**	**11.36**

For a soil type analysis, 1.5-acre plots were created in the treated and control strips with each 1.5-acre plot containing only Crosby or Brookston soil type. The results are found in figure 5.

Figure 5. Yield from Control and Treated Plots from Crosby and Brookston Soil Types.

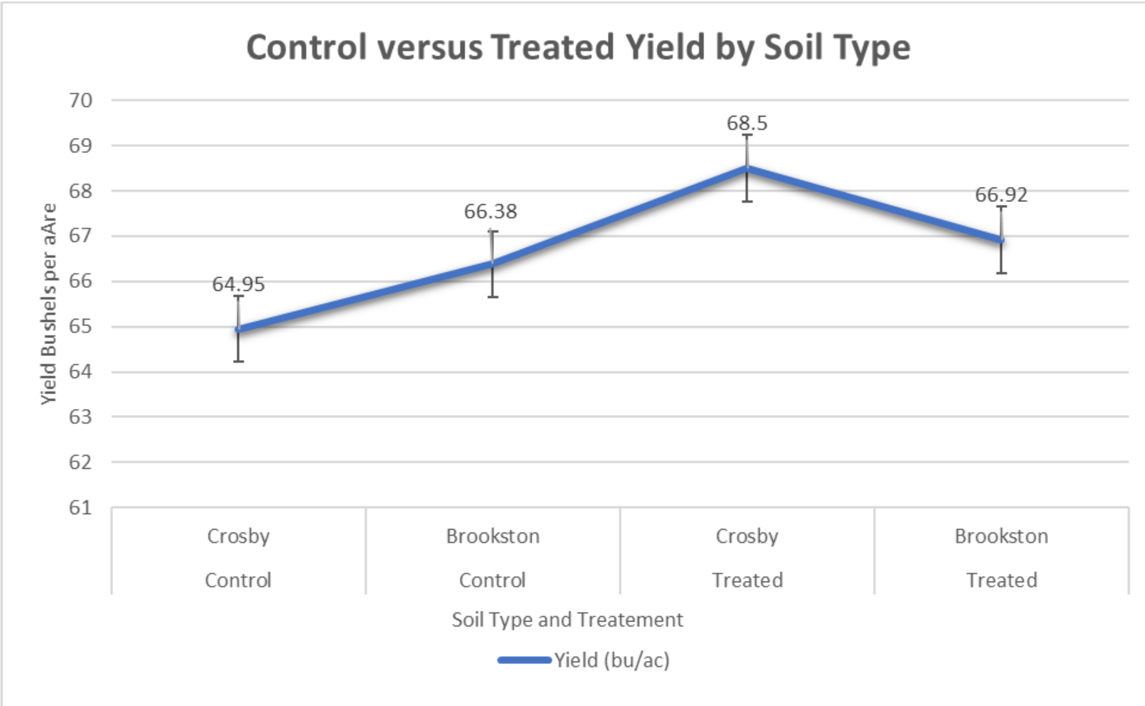
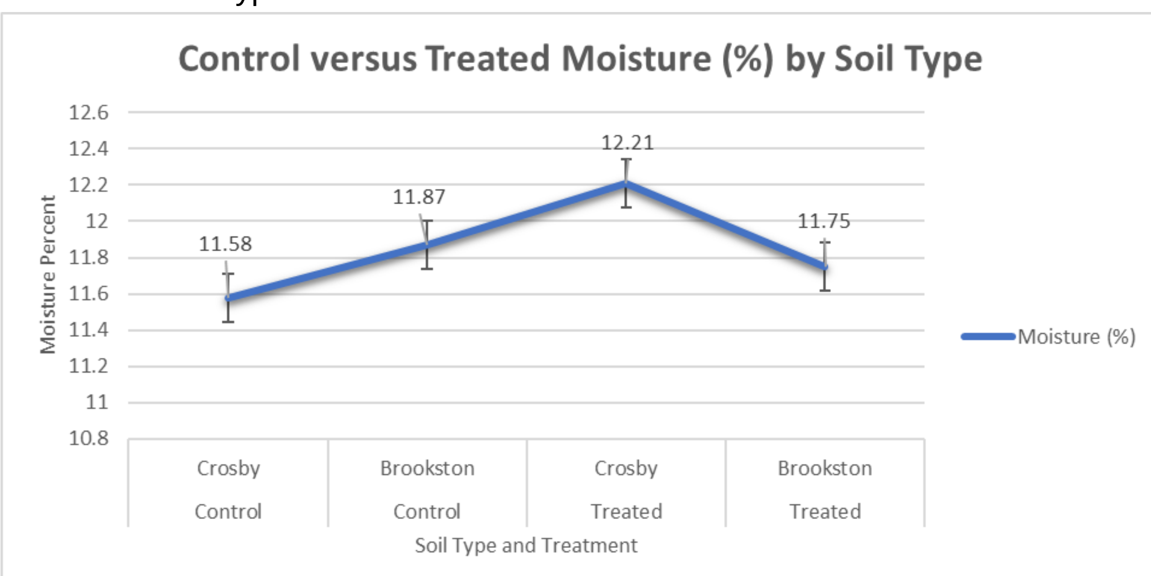


Figure 6. Grain Moisture from Control and Treated Plots from Crosby and Brookston Soil Types.



Along with yield, graphed on figure five, grain moisture is graphed as well in figure 6. Moisture has a direct relation to yield. As grain moisture rises yield rises as well, and as moisture decreases yield decreases. The ideal moisture is thirteen percent (Burr and Zoubek, 2014). Less than thirteen percent moisture results in yield reduction (Burr and Zoubek, 2014). At eleven percent and 12 percent moisture approximately 2.25 percent and 1.14 percent of yield was reduced, respectively (Burr and Zoubek, 2014). Although control plots had lower grain moisture than the treated plots, there was no significant difference in grain moisture contents between the control and treated plots on each soil type. The increased grain moisture content in controls could be because the AMS application increased the chlorophyll production and allowed the soybean plants stay greener longer and dry down was slowed.

Table 7. Statistical Analysis of Yield on Control and Treated Strips and Soil Type.

Parameter	T-value	P-value	df value	Reject or Accept Null Hypothesis
Yield: Control versus Treated Strips	0.226	0.838	2.59	Reject
Yield: Crosby versus Brookston Treated Plots	0.042	0.973	1.046	Reject

Figure 5 shows the control Crosby plot yielded 64.95 bushels per acre and treated Crosby plot had a yield of 68.50 bushels per acre. The yields for control and treated plots on Brookston soil type were 66.38 and 66.93 bushels per acre, respectively. Statistical analysis was unable to be performed on mean yields between the treated and control of each soil type separately because of only one data point. The two hypotheses of Crosby versus Brookston were tested. H_O: μCrosby = μBrookston the true population mean yield of the Crosby plots is the same as that of the Brookston plots. H_A: μCrosby $\neq$ μBrookston the true population mean yield of the Crosby plots is not the same as that of the Brookston plots. The p-value (0.973) > α (0.05) (table 7) and we fail to reject the null hypothesis. There is no significant difference in the true population mean yield between the Crosby and Brookston soil type plots.

The lack of yield response to AMS in Brookston soil types was attributed to a potential increase in sulfur mineralization from the organic matter found in Brookston. A higher yield response in Crosby was expected due to a lower organic matter content and consequently a lower sulfur mineralization in Crosby soil types. Organic matter was probably the cause for difference in yield response between the two soil types. The Brookston soil type is a loam while the Crosby soil type is a silt loam. The Brookston soil type was on average 1 percent higher in organic matter than the Crosby soil type. In conversations with the farmer, since there was not a significant yield increase across all soil types, it appeared there was no perceived economic benefit for the farmer to make the additional sulfur application.

Table 8. Economic Analysis of Crosby and Brookston Treated Plots.

Soil Type	Treatment	Change in Yield from Control	Market Price	Gross Revenue	Cost of AMS	Profit Loss
		bu/ac	$	$ per acre	$	$
Crosby	Treated	3.55	9.00	31.95	15.00	16.95
Brookston	Treated	0.54	9.00	4.86	15.00	(10.14)

Further analysis of economics showed a positive profit loss when AMS was applied to the Crosby soil type (table 8). There was an economic loss when AMS was applied to the Brookston soil type (table 8). Additional analysis on low organic matter soil types needs to be conducted to assure that a sulfur application provides a consistent yield increase to soybeans. This could mean looking at a variable rate application of sulfur instead of a uniform rate to gain the largest economic benefit.

Research Findings in the Consulting Business

The clientele in the agronomic consulting business can range from a 50-acre hobby farmer to a 20,000-acre farming operation. There are significant differences between every operation, but the commonality is on farm research. The Majority of successful operations run research plots in their fields. With every research plot a farmer learns one of three things: i) yes, this is good and I need to implement this on the whole operation; ii) no, this was not good and I should not try it again next year; or iii) no, this did not work but let us try again the following year. All these findings are good learnings to have on the operation. If operations are not learning, then they are not moving forward. The results from this research project may not have produced the statistical data that is conclusive, but it did give the consulting business answers for the clientele. This research sparked conversations on how to adapt to adverse weather. Research rarely ever goes as planned, but it provides options to create alternate plans that can adapt to the new environment. In table 7 the yield difference between the treated and control Crosby soil type was a 3.55-bushel yield difference. This means the gross revenue off the AMS treatment was $31.95 for the $9.00 a bushel price the farmer marketed their grain at. The yield difference between the treated and control Brookston soil type was 0.54 bushels and had a gross revenue of $4.86. This indicates that the AMS treatment to the Crosby soil type shows promise of profitability where the treatment to the Brookston soil type may not. Dollar figures are the language of consulting clientele. This knowledge of an AMS treatment having a significant increase in gross revenue when applied to Crosby soil types has sparked interest in more clients since this project.

Research Contributions to Soybean Production

Soybean production across the United States varies. Farmers use excuses of the ground is poor and there is not any way to produce a better soybean crop because of the poor ground. The research data produced from this field trial showed that the poor or unproductive soil type is where an economic yield response is often observed. This research will spark interest in managing soybeans more and more and fine-tuning variable rate fertilizer that is just not an option for major nutrients like phosphorous and potassium but can be applicable to secondary nutrients like sulfur and other micronutrients as well. The research is opening doors to new insights on nutrient management.

Acknowledgements

I would like to thank my major professor Dr. Renuka Mathur for all her guidance throughout my Creative Component and last year with Iowa State. Finally, I would like to thank my client for participating in the research trial. Without their support this project would not have been possible.

References

Barker, D.W and Sawyer, J.E. 2002. Sulfur Application to Corn and Soybean Crops in Iowa. Crop Manage. doi:10.31274/icm-180809-722

Bi, D., Hu, F., Xiao, X. and Zhao,Y. 2008. Effects of Sulfur Fertilization on Soybean Root and Leaf Traits, and Soil Microbial Activity. Plant Nutrition. 31: 473-483. doi: 10.1080/01904160801895001(3 March 2019)

Bradford, R.R. and Sharma, G.C. 2008. Effect of sulfur yield and amino acids of soybeans. Soil Science and Plant Analysis. 4: 77-82. doi: 10.1080/00103627309366421

Brady, N.C., and R.R. Weil. 2017. The nature and properties of soils (17th ed.). Prentice Hall, NJ.

Brady, N.C., and R.R. Weil. 2017. The nature and properties of soils (15th ed.). Prentice Hall, NJ.

Burr, C. and Zoubek, G. 2014. Managing Soybean Harvest Timing, Moisture to Improve Yield. https://cropwatch.unl.edu/managing-soybean-harvest-timing-moisture-improve-yield (5 November 2020)

Casteel S. and Camberato, J. 2017. Purdue Agronomy Extension. Purdue University, West Lafayette. https://www.agry.purdue.edu/ext/corn/news/timeless/sulfurdeficiency.pdf (18 March 2019)

Evans, S.D., Frazier, R.D. Ham, G.E., Liene, I.E. and Nelson, W.W. 1975. Yield and Composition of Soybean Seed as Affected by N and S Fertilization. AJ. 67:293-397. doi:10.2134/agronj1975.00021962006700030004x

Franzen, D.W. 2018. North Dakota State University Extension. North Dakota State University, Fargo. https://www.ndsu.edu/fileadmin/soils/pdfs/Limitations_of_Sulfate_2018.pdf (13 April 2019)

Gates, C.T. and Muller, W.J. 1979. Nodule and Plant Development in the Soyabean, *Glycine max* (L.) Merr.: Growth Response to Nitrogen, Phosphorus and Sulfur. Australian Journal of Botany. 27: 203-215. doi:10.1071/BT9790203

Grande, G.V. and Sweeney, D.W 2008. Yield, nutrient, and soil sulfur response to ammonium sulfate fertilization of soybean cultivars. Plant Nutrition. 16: 1083-1098. doi: 10.1080/01904169309364596

Guiteirrez Boem, F.H., Prystupa, P. and Ferraris, G. 2007. Seed Number and Yield Determination in Sulfur Deficient Soybean Crops. Plant Nutrition. 30: 93-104. doi: 10.1080/01904160601055095

Hitsuda, K., Ito, O., Subbarao, G.V. and Toriyama, K. 2008. Sulfur: A Missing Link between Soils, Crops, and Nutrition. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America. doi: 10.2134/agronmonogr50.c8

Harward, M.E., and H.M. Reisenauer. 1966. Reactions and movement of inorganic soil sulfur. Soil Sci. 101:326-335.

Kaiser, D.E. and Kim, K. 2013. Soybean Response to Sulfur Fertilizer Applied as a Broadcast or Starter Using Replicated Strip Trials. AJ. 105:1189-1198. doi: 10.2134/agronj2013.0023

Kyverga, P.M., Mueller, T.A., and Mueller, D.S. 2018. On-Farm Replicated Strip Trials. file:///C:/Users/abbyh/Downloads/books-acsesspublicati-precisionagbasics-precisionagbasics.2016.0096_On_Farm_Replicated_Strip_Trials.pdf (18 November 2020)

Marschner, H. 2012. Mineral Nutrition of Higher Plants (3rd ed.). Academic Press, NY.

Murphy, L.S., Paulsen, G.M. and Wooding, F.J. 1970. Response of Nodulated and Nonnodulated Soybean Seedlings to Sulfur Nutrition. AJ. 62: 277-280. doi: 10.2134/agronj1970.00021962006200020030x

National Atmospheric Deposition Program. 2002. National atmospheric deposition program 2001 annual summary. NADP data report 2002-01. Illinois State Water Survey, Champaign, IL. https://bqs.usgs.gov/acidrain/program.pdf (13 April 2019)

U.S. Department of Commerce and U.S. Department of Agriculture. 2019. Weekly Weather and Crop Bulletin. 106. 5. https://downloads.usda.library.cornell.edu/usda-esmis/files/cj82k728n/cr56n926h/8s45qk577/wwcb2219.pdf (27 July 2020)

Appendix 1: Soil Test Audit for Control and Treated Crosby and Brookston Soil Types

Sample Location	NW 1050 300		UT	UT	T	T	
Sample Identification			Crosby	Brooksto	Crosby	Brooksto	
Lab Number			1171-1	1172-1	1173-1	1174-1	
Total Exchange Capacity (ME/100 g)			10.89	18.15	10.85	15.65	
pH	Buffer (SMP/Sikora)		NA	7.4	NA	7.2	
	H_2O (1:1)		7.3	6.3	7.4	6.1	
Organic Matter (360°C LOI) %			2.22	3.29	1.91	3.40	
Estimated Nitrogen Release	lb/A		64	83	58	84	
ANIONS	SOLUBLE SULFUR*	ppm	6	8	13	12	
ANIONS — PHOSPHORUS	MEHLICH III	lb/A P as P_2O_5	82	380	73	238	
		ppm of P	18	83	16	52	
	BRAY II	lb/A P as P_2O_5					
		ppm of P					
	OLSEN	lb/A P as P_2O_5					
		ppm of P					
EXCHANGEABLE CATIONS	CALCIUM*	lb/A	2974	5606	2854	4784	
		ppm	1487	2803	1427	2392	
	MAGNESIUM*	lb/A	766	870	818	776	
		ppm	383	435	409	388	
	POTASSIUM*	lb/A	156	354	194	314	
		ppm	78	177	97	157	
	SODIUM*	lb/A	30	26	26	26	
		ppm	15	13	13	13	
BASE SATURATION PERCENT							
Calcium	%		68.27	77.22	65.76	76.42	
Magnesium	%		29.31	19.97	31.41	20.66	
Potassium	%		1.84	2.50	2.29	2.57	
Sodium	%		0.60	0.31	0.52	0.36	
Other Bases	%		NA	NA	NA	NA	
Hydrogen	%		0.00	0.00	0.00	0.00	
EXTRACTABLE MINORS							
Boron* (ppm)			0.42	0.71	0.49	0.52	
Iron* (ppm)			127	233	108	171	
Manganese* (ppm)			64	12	64	13	
Copper* (ppm)			4.68	8.15	5.59	7.07	
Zinc* (ppm)			1.62	3.01	2.12	3.09	
Aluminum* (ppm)			617	967	659	873	
OTHER TESTS	Soluble Salts (mmhos/cm)						
	Chlorides (ppm)						

a - alkaline soil

* Mehlich III Extractable

Appendix 2: Tissue Test Report Treated Brookston and Crosby Soil Types

Lab Number		10337			10338
Location		NW 1050 300			NW 1050 300
Description		T Brookston 1			T Brooston 2
Plant Part		Whole Plant/Upp			Whole Plant/Upp
PERCENTAGES (%)					
NITROGEN	(N)	6.17	NITROGEN	(N)	6.04
PHOSPHORUS	(P)	0.450	PHOSPHORUS	(P)	0.459
POTASSIUM	(K)	1.88	POTASSIUM	(K)	1.82
CALCIUM	(Ca)	1.02	CALCIUM	(Ca)	1.14
MAGNESIUM	(Mg)	0.416	MAGNESIUM	(Mg)	0.449
SULFUR	(S)	0.333	SULFUR	(S)	0.314
PARTS/MILLION (ppm)					
BORON	(B)	43.5	BORON	(B)	43.9
IRON	(Fe)	102.0	IRON	(Fe)	90.6
MANGANESE	(Mn)	32.9	MANGANESE	(Mn)	36.2
COPPER	(Cu)	9.0	COPPER	(Cu)	8.3
ZINC	(Zn)	42.2	ZINC	(Zn)	42.0
ALUMINUM	(Al)	24.1	ALUMINUM	(Al)	19.4
SODIUM	(Na)	< 10.0	SODIUM	(Na)	17.9

Lab Number		10339			10340
Location		NW 1050 300			NW 1050 300
Description		T Crosby 1			T Crosby 2
Plant Part		Whole Plant/Upp			Whole Plant/Upp
PERCENTAGES (%)					
NITROGEN	(N)	6.16	NITROGEN	(N)	5.95
PHOSPHORUS	(P)	0.446	PHOSPHORUS	(P)	0.459
POTASSIUM	(K)	1.75	POTASSIUM	(K)	1.72
CALCIUM	(Ca)	1.19	CALCIUM	(Ca)	1.07
MAGNESIUM	(Mg)	0.466	MAGNESIUM	(Mg)	0.458
SULFUR	(S)	0.362	SULFUR	(S)	0.336
PARTS/MILLION (ppm)					
BORON	(B)	40.7	BORON	(B)	39.4
IRON	(Fe)	109.0	IRON	(Fe)	92.3
MANGANESE	(Mn)	42.8	MANGANESE	(Mn)	37.9
COPPER	(Cu)	9.0	COPPER	(Cu)	8.5
ZINC	(Zn)	41.2	ZINC	(Zn)	36.9
ALUMINUM	(Al)	16.9	ALUMINUM	(Al)	14.0
SODIUM	(Na)	18.2	SODIUM	(Na)	< 10.0

Appendix 3: Tissue Test Report Control Brookston and Crosby Soil Types

Lab Number		10343			10344
Location		NW 1050 300			NW 1050 300
Description		UT Brookston 1			UT Brookston 2
Plant Part		Whole Plant/Upp			Whole Plant/Upp
PERCENTAGES (%)					
NITROGEN	(N)	6.11	NITROGEN	(N)	6.08
PHOSPHORUS	(P)	0.460	PHOSPHORUS	(P)	0.463
POTASSIUM	(K)	2.22	POTASSIUM	(K)	2.37
CALCIUM	(Ca)	1.07	CALCIUM	(Ca)	0.98
MAGNESIUM	(Mg)	0.371	MAGNESIUM	(Mg)	0.362
SULFUR	(S)	0.292	SULFUR	(S)	0.293
PARTS/MILLION (ppm)					
BORON	(B)	41.4	BORON	(B)	39.8
IRON	(Fe)	87.6	IRON	(Fe)	90.5
MANGANESE	(Mn)	29.7	MANGANESE	(Mn)	28.3
COPPER	(Cu)	8.3	COPPER	(Cu)	8.6
ZINC	(Zn)	41.1	ZINC	(Zn)	38.5
ALUMINUM	(Al)	12.2	ALUMINUM	(Al)	16.1
SODIUM	(Na)	11.5	SODIUM	(Na)	< 10.0

Lab Number		10341			10342
Location		NW 1050 300			NW 1050 300
Description		UT Crosby 1			UT Crosby 2
Plant Part		Whole Plant/Upp			Whole Plant/Upp
PERCENTAGES (%)					
NITROGEN	(N)	5.68	NITROGEN	(N)	5.71
PHOSPHORUS	(P)	0.429	PHOSPHORUS	(P)	0.480
POTASSIUM	(K)	1.42	POTASSIUM	(K)	1.41
CALCIUM	(Ca)	1.11	CALCIUM	(Ca)	1.08
MAGNESIUM	(Mg)	0.534	MAGNESIUM	(Mg)	0.519
SULFUR	(S)	0.318	SULFUR	(S)	0.329
PARTS/MILLION (ppm)					
BORON	(B)	44.0	BORON	(B)	42.4
IRON	(Fe)	100.0	IRON	(Fe)	97.6
MANGANESE	(Mn)	51.3	MANGANESE	(Mn)	41.8
COPPER	(Cu)	8.0	COPPER	(Cu)	8.2
ZINC	(Zn)	39.0	ZINC	(Zn)	37.7
ALUMINUM	(Al)	17.1	ALUMINUM	(Al)	20.2
SODIUM	(Na)	< 10.0	SODIUM	(Na)	17.2

Appendix 4: Timeline of Operations

Date to Complete	Description of Task
April 2019	Sign Farmers up For INfield Advantage Strip Trials
April – May 2019	Plant Soybean Fields
April – May 2019	Build Replicated Strip Trial Prescriptions
April – May 2019	Send off Prescriptions
April – May 2019	Apply 100 lbs of AMS Strip Trials
June 2019	Finish Signing Farmers up with INfield Advantage
July 2019	Tissue Sample Strip Trials
July – August 2019	Fly Drone for Aerial Imagery of Fields
September – October 2019	Harvest AMS Strip Trials
October 2019	Collect Harvest Data
November – December 2019	Analyse data and statistics from Strip Trials.
January 2020	Meet with Clients to Discuss Strip Trial Results